Diboson WZ Production and Resonances

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Overview

- Why Look at WZ Resonances?

- Signatures

- Analysis Procedure

- Results

- Limits

- 2011 Dataset

- Outlook

WZ Resonances

We expect WZ diboson production from the standard model. It is one of the few ways to get three high energy leptons in an event.

This makes it a very interesting and clean signal to study

It also makes it important for any new physics searches with several high energy leptons.

If electroweak symmetry is broken dynamically, we could see a strongly interacting sector that couples to the weak bosons.

This gives a whole category of models that could produce WZ resonances.

How do we probe this signature? What motivates it? What have we measured?
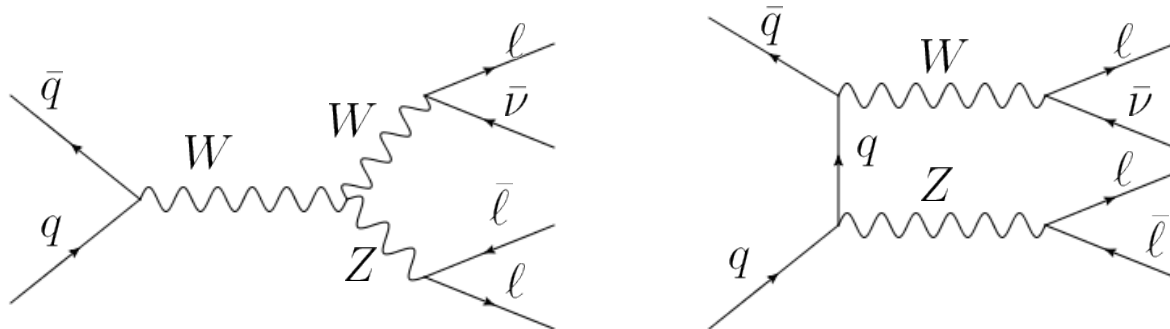
Resonances Motivation

Why look for new physics in diboson resonances?
(The hand-wavey version)

• We observe the breaking of the electroweak symmetry: The W and Z bosons have mass.

• We can break the electroweak symmetry through some strong coupling sector at the appropriate scale

• We know generally what a strongly coupled theory looks like, see QCD

• In particular, a strongly coupled theory should have bound states that we will observe as resonances

• To break EW symmetry, we need these resonances to couple to W and Z bosons

• The most common model of this type is Technicolor, which introduces a new strong SU(N) sector at ~ Λ_{EW}

SM Higgs vs Technicolor

- **simple and economical**

- **GIM mechanism, no FCNC problems, EW precision data are OK for preferably light Higgs boson**

- **SM is established, perfectly describes data**

- **fine-tuning and naturalness problem**

- **there is no example of fundamental scalar**

- **Scalar potential parameters and yukawa couplings are inputs**

- **complicated at the effective theory level**

- **FCNC constraints requires walking, potential tension with EW precision data**

- **no viable ETC model suggested yet, work in progress**

- **no fine-tuning, the scale is dynamically generated**

- **Superconductivity and QCD are examples of dynamical symmetry breaking**

- **parameters of low-energy effective theory are derived once underlying ETC is constructed**

Technicolor Phenomenology

• What would the dynamical symmetry breaking in Technicolor look like in a detector?

• New strong coupling sector gives technicolor resonances

• Like ρ, π in QCD

π^+ 140 MeV

ρ^+ 770 MeV

• The vector and axial vector techni-particles can decay to W and Z

• Eg. Given a new gauge sector that becomes strong at ~1 TeV, we can start looking for these resonances at a few hundred GeV

What Else WZ Resonantly?

Technicolor: Which is very good at giving masses to W and Z bosons, but struggles with fermions.

W': From an extra SU(2) gauge symmetry, or extra dimensions

Charged Higgs: Not in most theories, but we can twist things so that this is possible

Anomalous TGC: Not a resonance, but would catch new physics going to WZ

The ATLAS Detector

ATLAS is a general purpose detector at the LHC. It contains many specialized subdetectors, built out from the interaction point. It is nearly hermetic, with tracking out to10 degrees (eta = 2.5) from the beam direction, and calorimetry out to 1 degree(eta = 4.9) from the beam direction.

From inside to out, the detector layers do: tracking, calorimetery, and muon Identification.
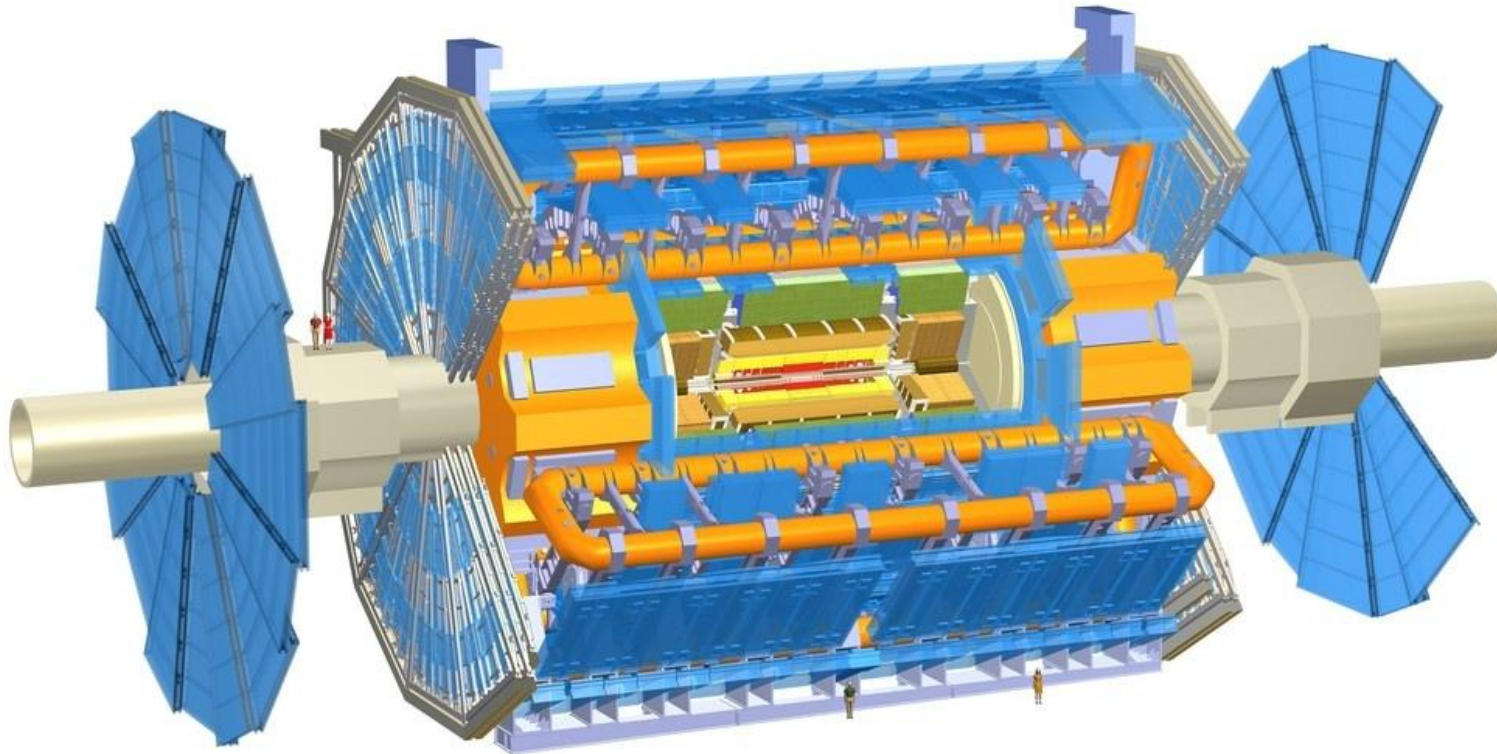
Objects in ATLAS

The components of the ATLAS detector build particles from various parts of the detector.

Electrons will leave a track in the inner detector, and energy as they shower in the EM calorimeter

Muons will leave a track in the ID, but will pass through the calorimeters, leaving hits in the muon system

Colored Particles will form **jets** of hadrons, that give clumps of energy in the calorimters and clusters of tracks.

Photons will leave energy as they shower in the EM cal, but no track in the inner detector
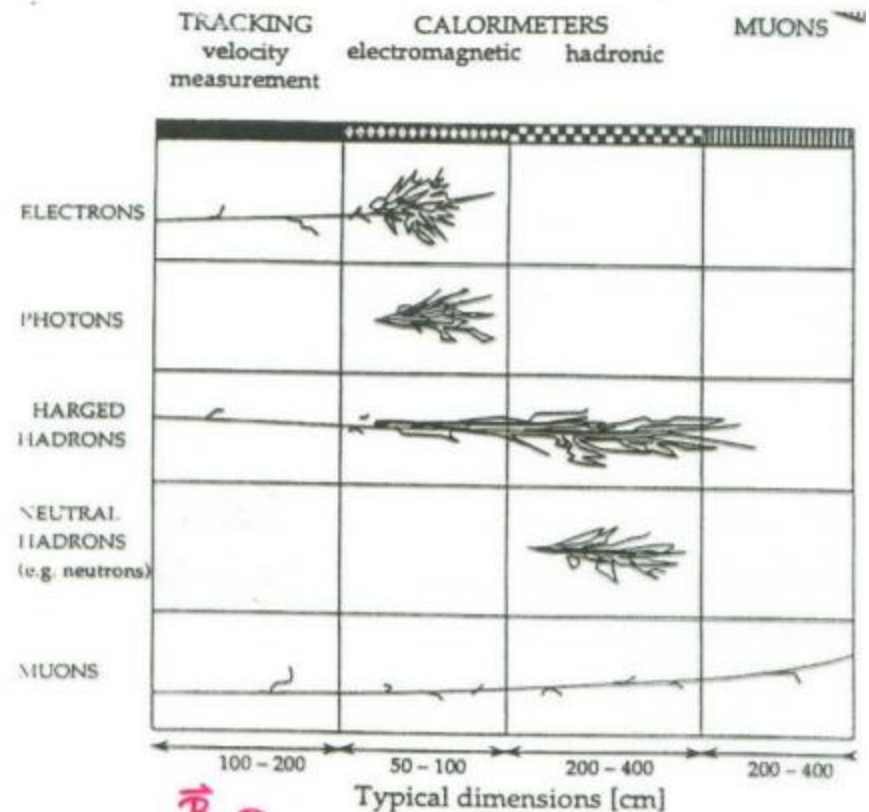
Werner Riegler, CERN Lectures, 2009

Missing Transverse Energy

An imbalance of momentum suggests the presence of a neutrino, passing undetected from our detector.

By adding together our stopped particles (from the calorimters) and our escaping particles (from the muon system), we can reconstruct the momentum of any invisible particle in two directions.

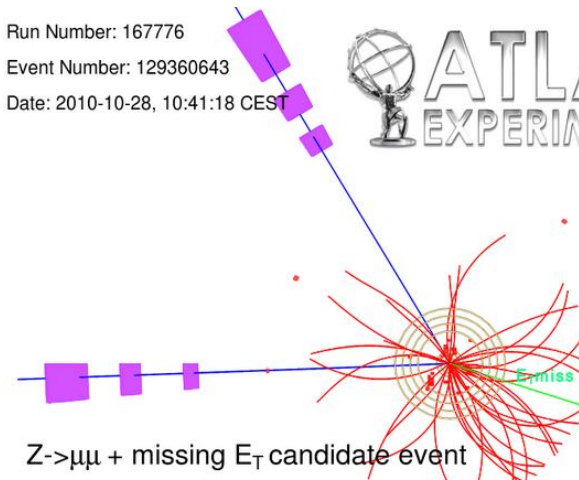We don't know how much energy is lost down the beam pipe, so we can't reconstruct that direction

For our analysis then, in addition to the physics objects above, we can consider missing transverse energy in processes that produce real neutrinos.
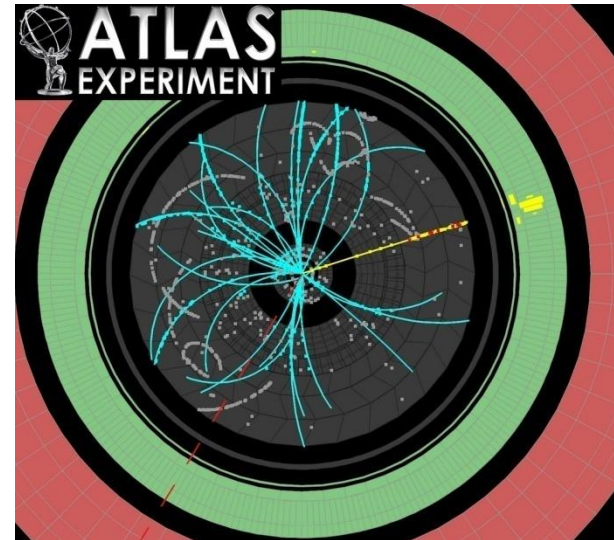
Run Number: 167776
Event Number: 129360643
Date: 2010-10-28, 10:41:18 CEST

$Z \rightarrow \mu\mu$ + missing E_T candidate event

2011 Luminosity
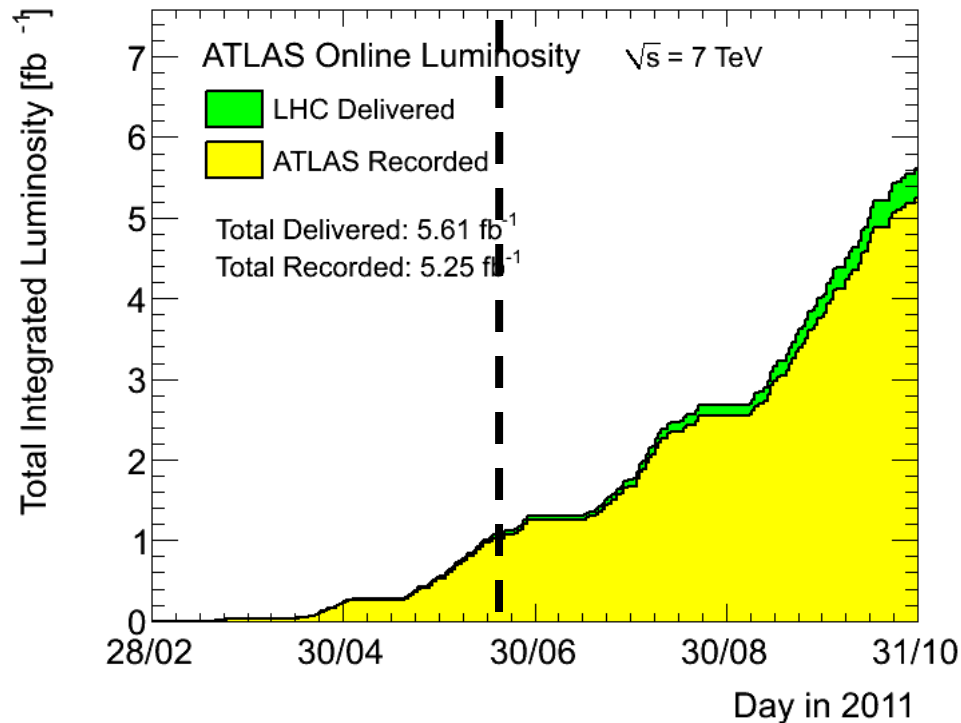
The LHC has had a very impressive p-p run in 2011.

Most analyses so far have been done on the first 1fb-1, including the results shown here.

These data have given many standard model measurements and exotics exclusions. But we have 5 times the data to work with now.

Event Selection

Look for **3 electrons or muons** with **pT > 15 GeV**

Require that they be inside the tracking volume, η **< 2.5**

Require that they be **isolated** from other tracks (μ) or energy (e)

Require a missing transverse energy **ET$_{Miss}$> 25 GeV** in the event (neutrino from W)

Form a Z boson candidate from appropriate leptons.
Require that this Z candidate has a mass close to the Z mass (**Δm < 10 GeV**)

W candidate from the remaining lepton and the missing energy (**mT > 20 GeV)**
With no mass peak, require tighter cuts on the third lepton (**pt > 20 GeV**, ID)

μ⁻

e

MET

μ⁺

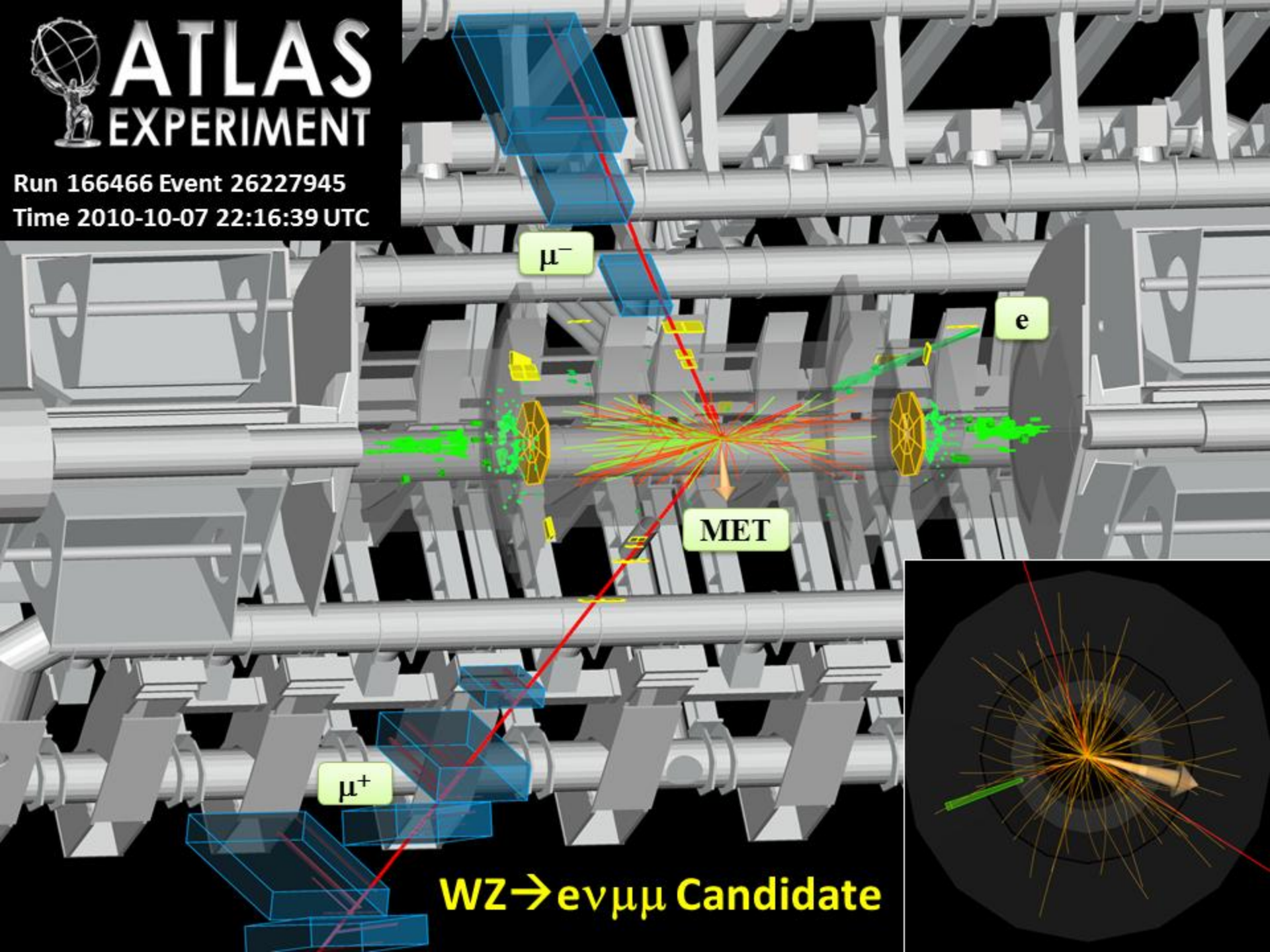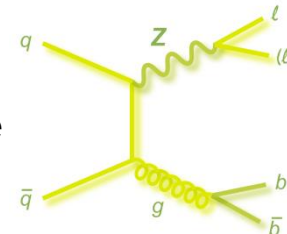WZ→eνμμ Candidate
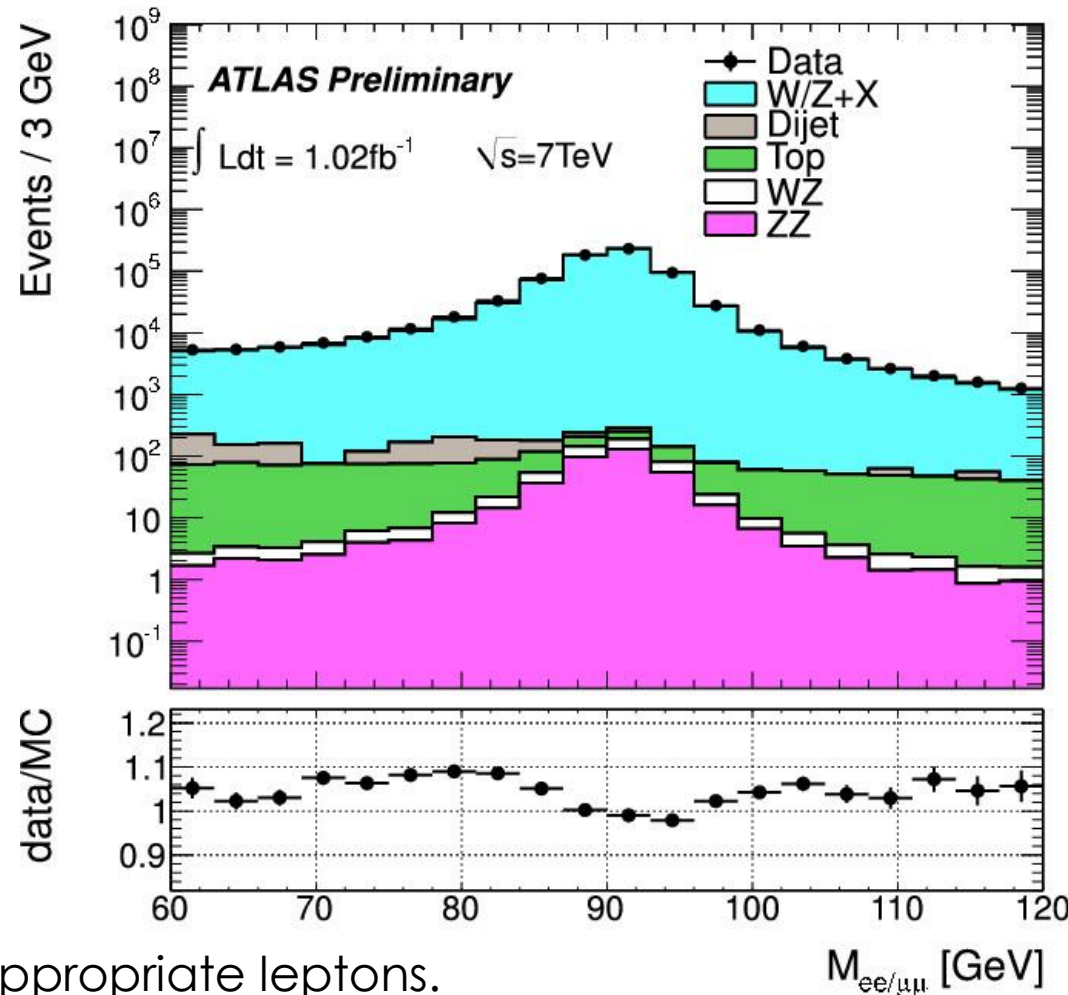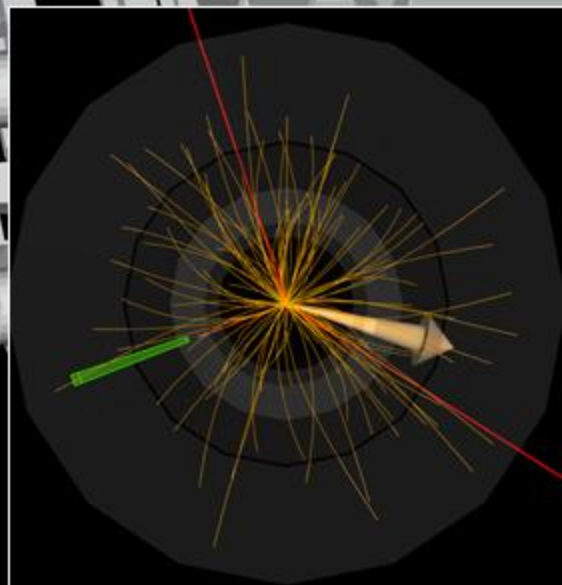
Backgrounds

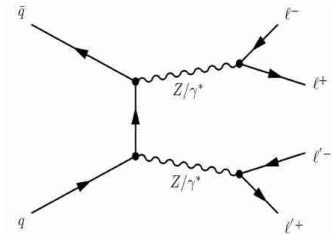Because fake leptons are fairly rare, we look mostly to events with 2 real leptons:

Z+jets:
  -Two real leptons on the Z peak with a very high rate
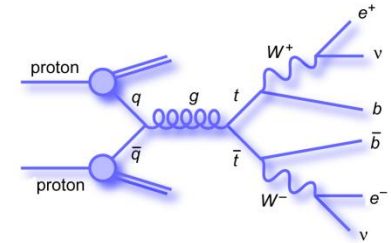 -Third lepton must be faked, expect low MET

ZZ:
  -Can have 4 real leptons in the event, no need for a lepton fake
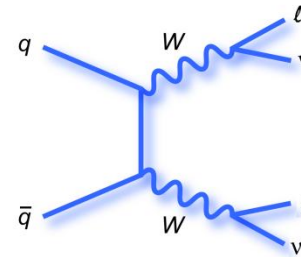 -Cross section is small, expect low MET

Top Quark Pairs:
  -Two real leptons, plus real missing energy. b quarks can fake l
  -Not produced on the Z mass, expect significant jet activity.

WW:
  -Two real leptons, real missing energy
  -Need to fake third lepton, not on Z mass

Data Driven Backgrounds

Fake* leptons tend to be badly modeled by Monte Carlo. We try to estimate these backgrounds from data.

(*Fake muons are very rarely 'fake', in that they leave a muon-like signature but are not a muon. Generally, we are more concerned with non-prompt muons, eg: from b-quark decays)

Z+jets:
  -Use Z + low missing energy as a control region, containing very little true WZ
  -Trust that we have a real Z, consider only the third 'lepton'
  -Measure the ratio of tight (passing many object criteria) to loose in this region
  -Use this ratio to scale the number of Z + high missing energy + loose leptons
  -Z + high MET + loose is also background dominated
  -This scaling gives the number of signal events which come from Z + fake lepton

Top Quark Pairs:
  -Invert the Z mass window
  -The sidebands are dominated by ttbar, with a fake third lepton
  -Often, a fake lepton from b decays in (t -> Wb)
  -Interpolate between the high and low mass sidebands
  -Given all other cuts

Systematics

From Objects:
  -Muons: Reconstructed muons come with energy and efficiency uncertainty

  -Electrons: Reconstructed electrons come with energy and efficiency uncertainty

  -Missing Energy: Built from many other objects, MET absorbs systematics from the uncertainties in all of these (scale and resolution of various objects)

From the Detector:
  -Trigger: We rely on a single lepton trigger to select the events in question, which has a non-unity and somewhat uncertain effeciency

  -Luminosity: The total delivered luminosity has some uncertainty, which propagates to many measurements.

Theory:
  -Since we use some MC, we check the effects of varying these parameters, including: Renormalization scale, factorization scale, PDF uncertainties.
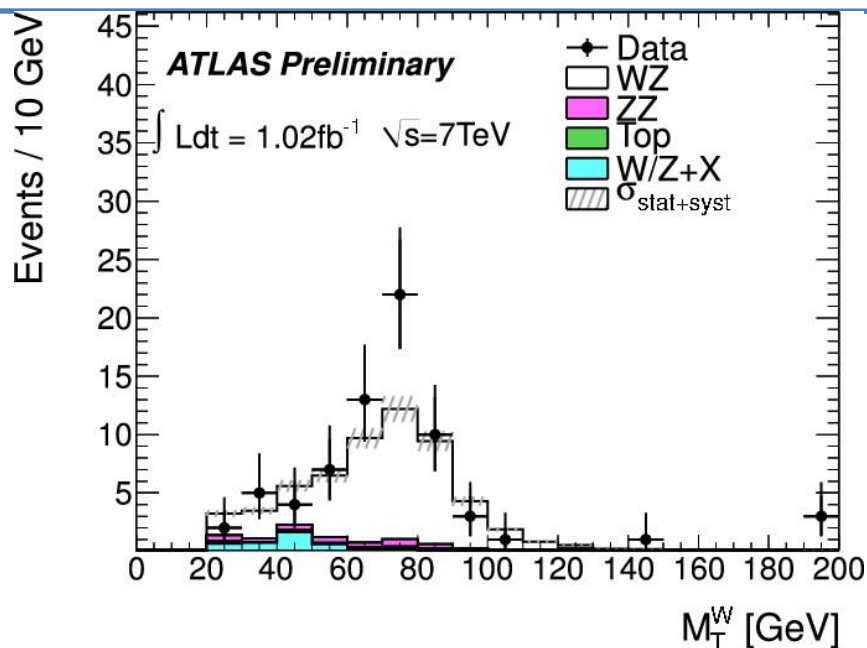
Cutflow
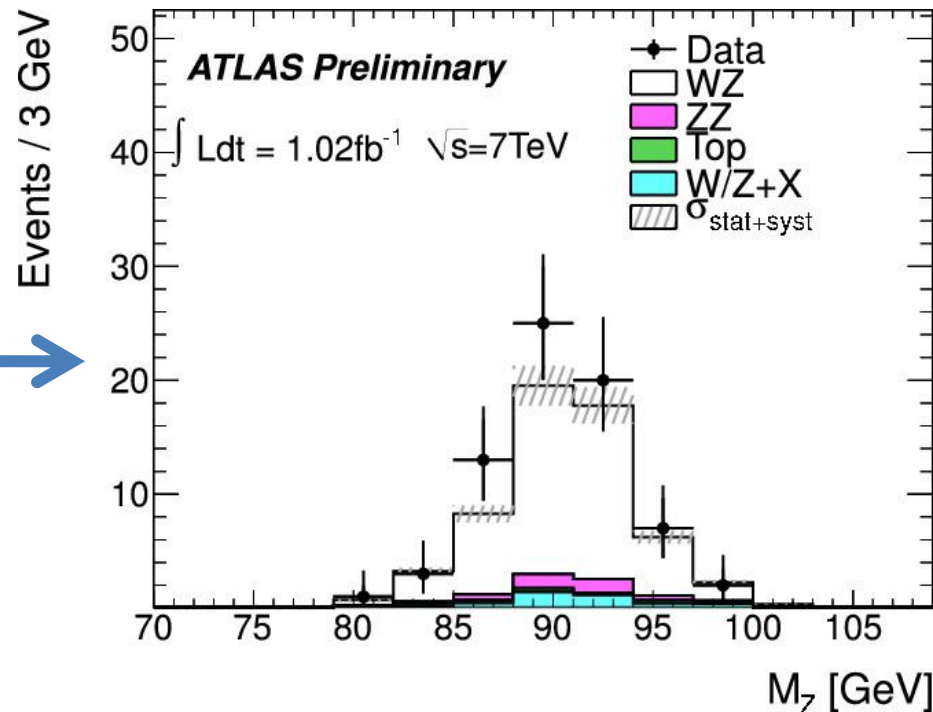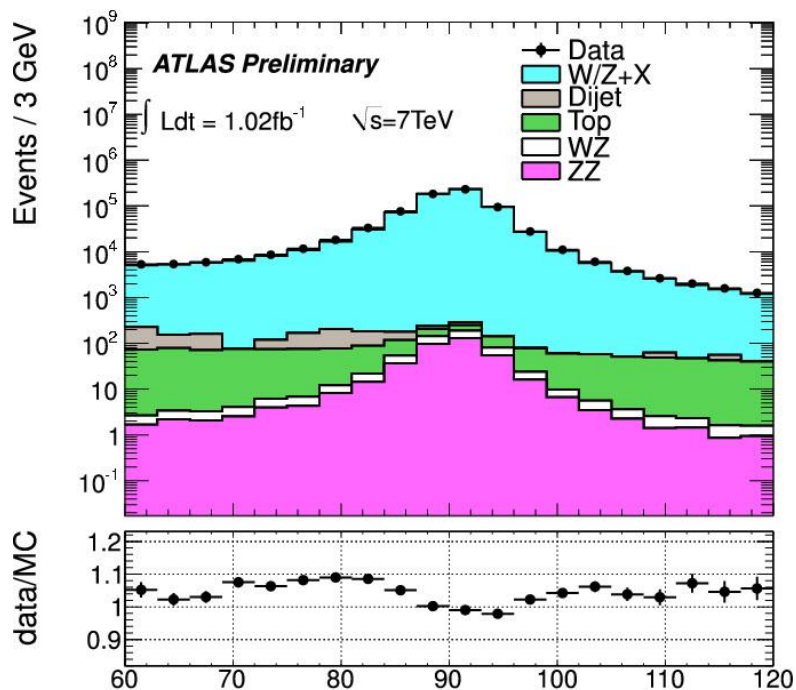
Cut	Cumulative Acceptance	Relative Acceptance
μ or e trigger	78.9	78.9
Primary Vertex	78.7	99.8
$|M_{\ell\ell} - M_Z| < 10$ GeV	28.2	35.8
Three Leptons	12.3	43.7
$E_T^{miss} > 25$ GeV	10.0	81.2
$M_T^W > 20$ GeV	8.5	84.9
Trigger Match	8.4	99.5

From a preselection that is dominated by Z events, these cuts gives a nearly background-free sample.
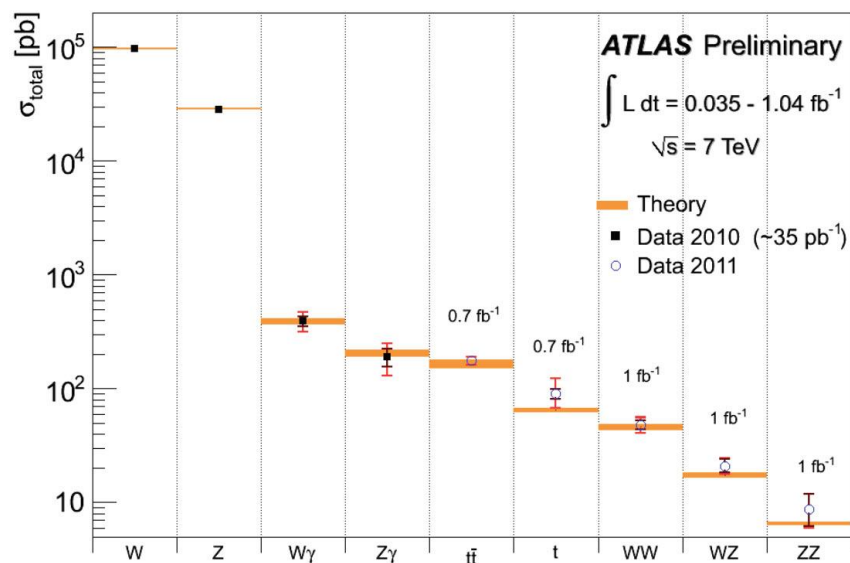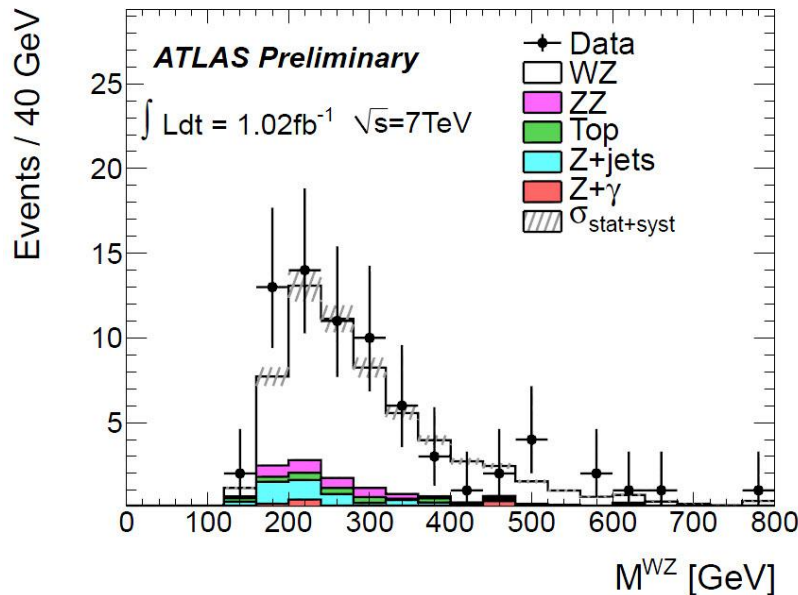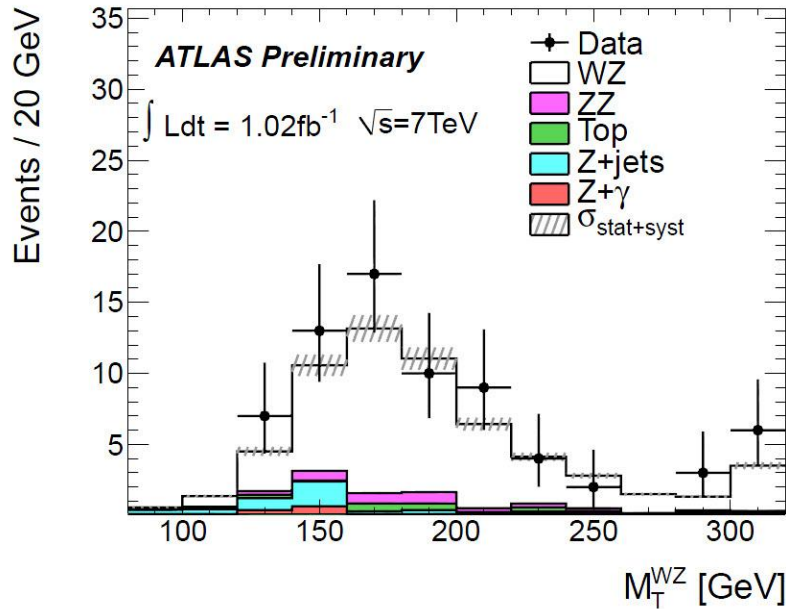
Standard Model WZ Results

On our way to resonant WZ production, we should stop by the standard model results.

The standard model Diboson measurements have some of the smallest cross sections at the LHC

The clean signature means that we can see them before we are able to resolve larger cross section processes.

Bump Hunting

Once we have our WZ candidates, we can easily build a transverse mass.

The neutrino from the W means that some of our signal comes from missing transverse energy, so we have no Z component.
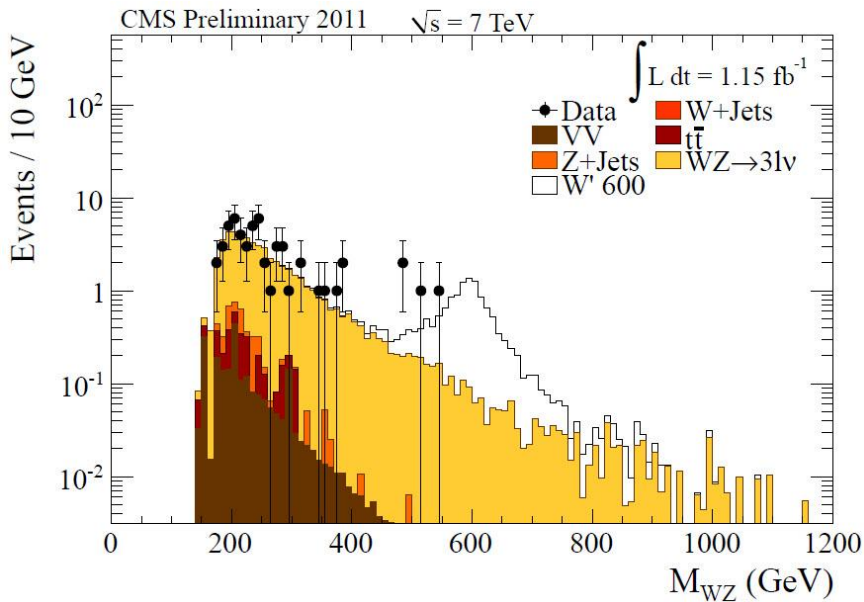
Unless we assume that the W was on shell. In that case, we have two possible $p_Z(\nu)$ solutions

Picking the smaller solution is correct in simulation 75% of the time.

No obvious bumps though

Bump Hunting Results

CMS Preliminary 2011 $\sqrt{s}$ = 7 TeV

$\int L\,dt = 1.15\,\text{fb}^{-1}$

Events / 10 GeV

Data — W+Jets — VV — $t\bar{t}$ — Z+Jets — WZ→3lν — W' 600

M_{WZ} (GeV)

CMS Preliminary 2011 $\sqrt{s}$ = 7 TeV

$\int L\,dt = 1.15\,\text{fb}^{-1}$

Events / 10 GeV

Data — W+Jets — VV — $t\bar{t}$ — Z+Jets — WZ→3lν — W' 600

Lepton Pt Sum: H_T (GeV)

A resonance decaying to WZ would stick out fairly cleanly above the standard model spectrum
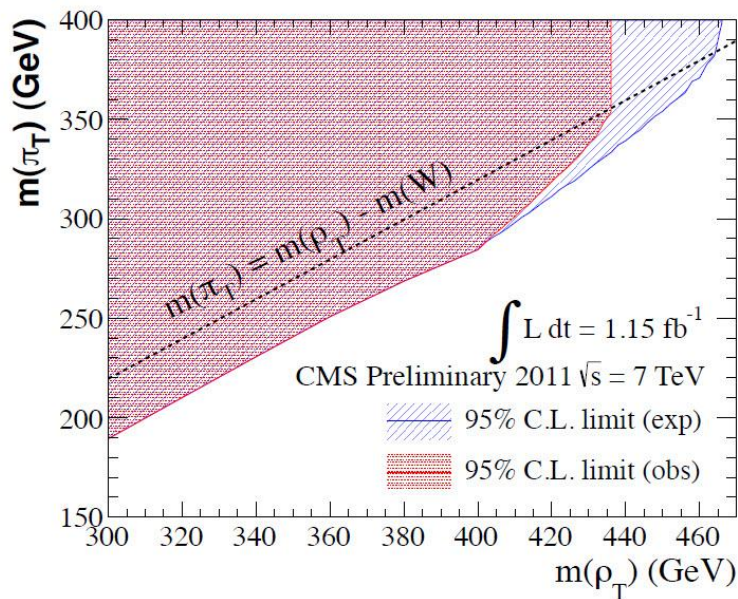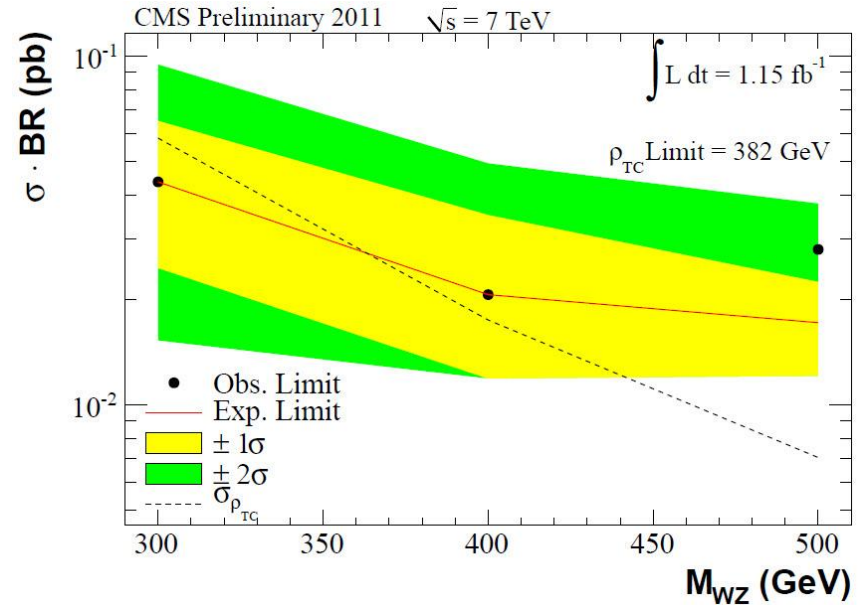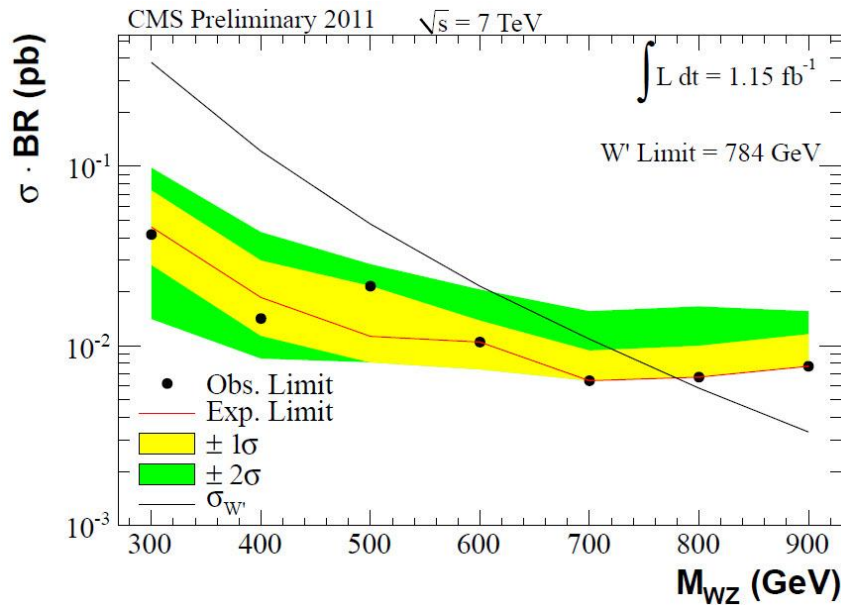
Additionally, high mass resonances can be selected by requiring a lepton sum p_T

Still no bumps in data though.
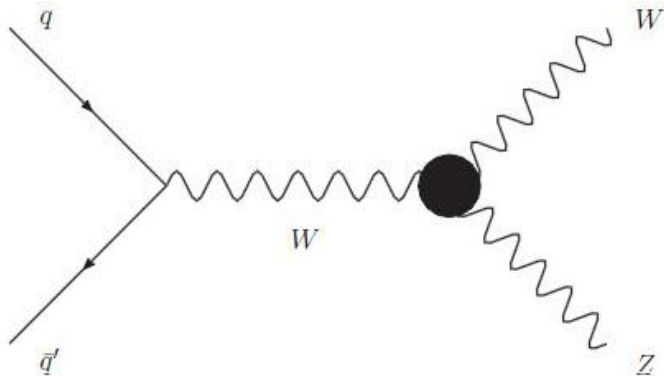
Still, we can use these results to set limits.
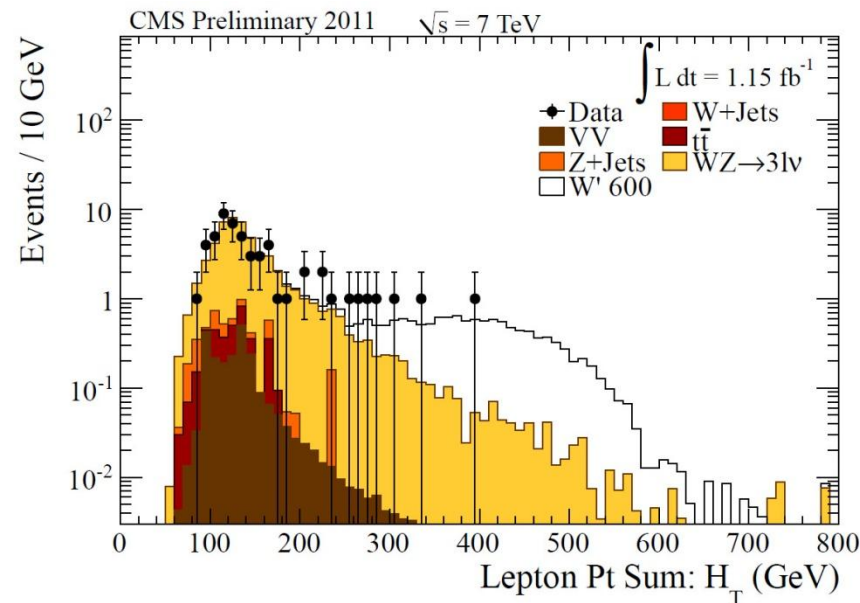
Limits

Given a technicolor or W' model, we can set limits on the production cross section.

Technicolor models are accessible only as long as the ρ_{TC} decays to WZ.

When $\rho_{TC} \to W\pi_{TC}$ is allowed, WZ channels are suppressed
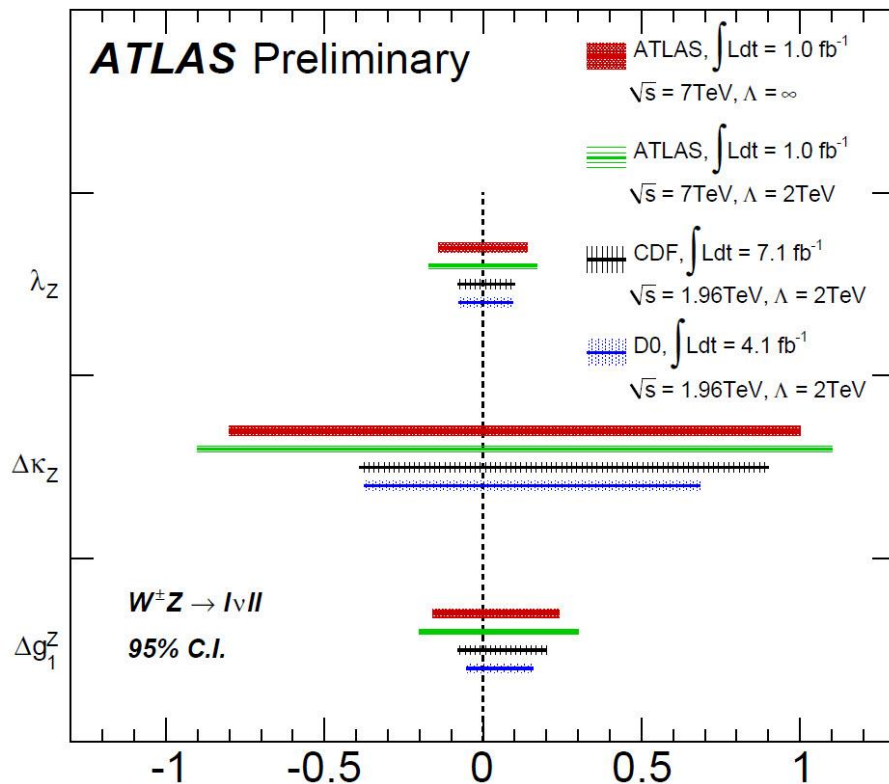
Anomalous TGC

In addition to resonant production, we can look for anomalous production in the standard model.
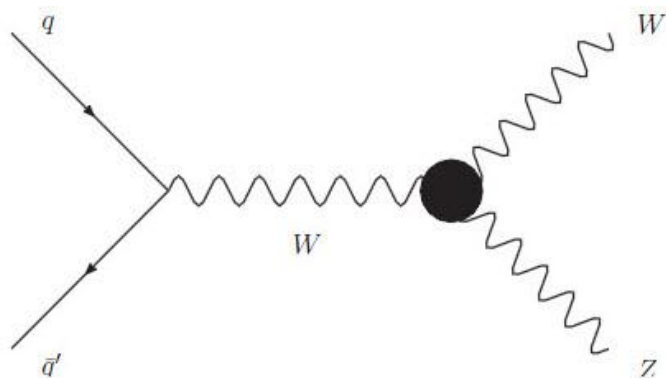
The triple gauge boson vertex is associated with several terms in the lagrangian.

We fit the total number of observed events to set limits on the deviation of these couplings from the standard model values.

Limits are set for each term individually.

Anomalous TGC Improvements

aTGC limits will be improved by considering sensitive kinematic distributions.

Because the TGC appears in s-channel production, anomalies in this value will be more evident in the high pT tail.

The pT of the reconstructed Z boson can be used to improve the aTGC sensetivity.

aTGC limits give a model independent characterization of new physics that might be decaying to WZ.
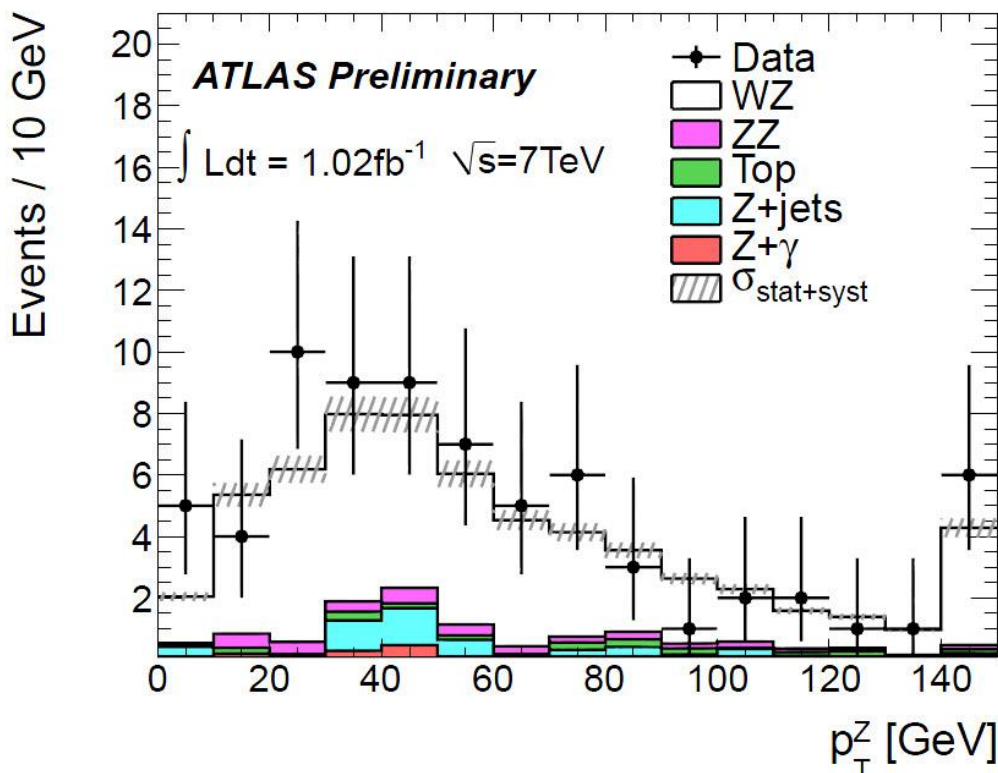
2011 Dataset Prospectives

All of this has been with the first fb-1

Including the full 2011 data will significantly improve their reach.

Additionally, improvements in the analysis (like using kinematics for WZ aTGC) will push these analyses even further.
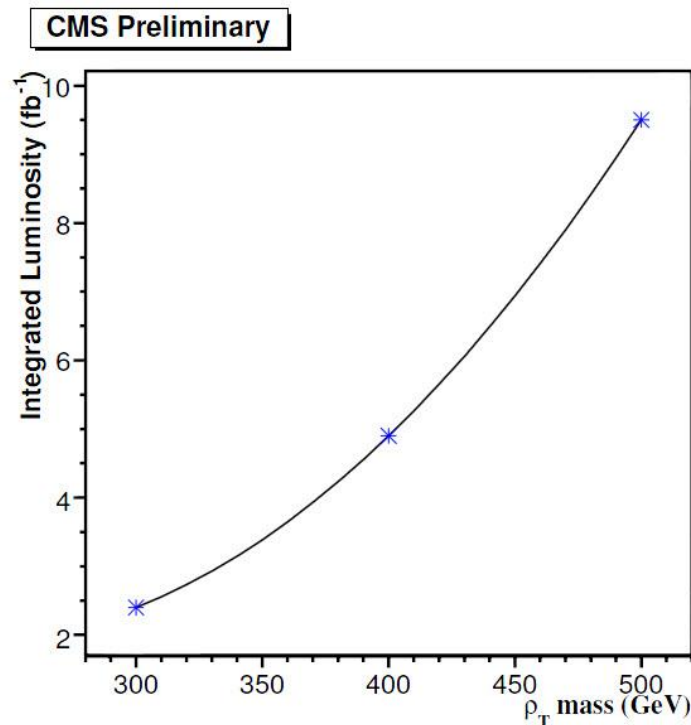

Figure 8: Integrated luminosity needed to reach 5σ significance as a function of ρ_T mass.

Conclusions and Outlook

Standard model WZ is an important measurement in itself

We have cleanly measured the standard model WZ production using the first bit of the 2011 data

No resonant production yet, but lots more data to consider.

Resonances could come from many theories, dynamical electroweak symmetry breaking is one of the most interesting.

Additionally, anomalous triple gauge couplings give a model independent way to look for new physics producing WZ

This sector provides an interesting bridge between standard model and exotics measurements.